ARR No. E4G13

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

July 1944 as
Advance Restricted Report E4G13

THE EFFECT OF PISTON-HEAD TEMPERATURE ON KNOCK-LIMITED POWER

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ADVANCE RESTRICTED REPORT

THE EFFECT OF PISTON-HEAD TEMPERATURE ON KNOCK-LIMITED POWER

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SUMMARY

Object. - To determine the effect of piston-head temperature on knock-limited power.

Scope. - Tests were made in a supercharged CFR engine over a range of fuel-air ratios from 0.055 to 0.120, using S-3 reference fuel, AN-F-28, Amendment-2, aviation gasoline, and AN-F-28 plus 2 percent xylidines by weight. Tests were run at a compression ratio of 7.0 with inlet-air temperatures of 150° F and 250° F and at a compression ratio of 8.0 with an inlet-air temperature of 250° F. All other engine conditions were held constant. The piston-head temperature was varied by circulation of oil through passages in the crown of a liquid-cooled piston. This method of piston cooling decreased the piston-head temperature about 80° F. The data are not intended to constitute a recommendation as to the advisability of piston cooling in practice.

Summary of results. - The following results were obtained from this investigation:

1. Near the stoichiometric mixture, the percentage increase in knock-limited indicated mean effective pressure accompanying the decrease in the piston-head temperature of approximately 80° F was from 5 to 18 percent. At a fuel-air ratio of 0.10, the increase was from 0 to 10 percent.

2. Changes in piston-head temperature had no effect on indicated specific fuel consumption or on the general shape of the curves of knock-limited indicated mean effective pressure plotted against fuel-air ratio.

3. The effect of piston cooling on the knock-limited indicated mean effective pressure was greater for AN-F-28, Amendment-2, aviation gasoline and AN-F-28 plus 2 percent xylidines by weight than for S-3 reference fuel.

Conclusion. - For all but the high fuel-air ratios tested, the decrease in piston-head temperature permitted approximately 30 percent of the increase in knock-limited indicated mean effective pressure that was allowed by an equal decrease in inlet-air temperature.

INTRODUCTION

The effect of piston temperature on knock-limited power is part of the general problem of the relation of engine temperature to knock-limited performance. The problem is of interest from the considerations of increasing knock-limited power and of correlating fuel ratings on different engines.

Data on the effects of cylinder-head temperature have been conducted by the Pratt & Whitney Aircraft Division and submitted to the Coordinating Research Council. Tests on this phase of the problem are also being conducted at the Aircraft Engine Research Laboratory of the NACA.

The tests reported herein were made on three fuels at three sets of engine conditions to determine the effect of piston-head temperature on knock-limited power. Because the data were obtained from a small-scale (CFR) engine, the results are not directly applicable to a full-scale aircraft engine and should therefore be considered in such an application on a qualitative rather than a quantitative basis.

The work was conducted at the Aircraft Engine Research Laboratory at Cleveland, Ohio. The data were obtained during the period from January 26 to February 2, 1944.

APPARATUS AND TEST PROCEDURE

The tests were made on a high-speed, supercharged CFR engine coupled to a 100-horsepower, direct-current, cradle-type dynamometer. The engine was equipped with a sodium-cooled exhaust valve and a cylinder with four spark-plug holes. Champion RJ-11 spark plugs were used.

Knock was detected by a cathode-ray oscilloscope in conjunction with a magnetostriction pickup unit. Oil and inlet-air temperatures were measured with iron-constantan thermocouples and a self-balancing potentiometer. Figures 1, 2, and 3 are schematic diagrams of the fuel system, the inlet-air system, and the arrangement of spark plugs and pickup unit in the cylinder, respectively.

Figure 4 is a drawing of the liquid-cooled piston that provided the means for varying the piston temperature. In operation, cooling oil passed continuously from the hollow crankshaft (jets removed), through the drilled connecting rod and the wrist pin, and thence through the piston oil passages to the crown. After traversing the spiralled groove in the piston crown, the oil passed through the outlet hole and back into the crankcase. When piston cooling was not desired, a standard (not drilled) CFR wrist pin was installed in the same piston without removing the ring band from the cylinder.

A chromel-constantan thermocouple, which was peened in the center of the piston head 1/16 inch from the top surface, measured the piston-head temperature. At the bottom of the piston stroke, for about 10° of crank angle, the lead wires from the thermocouple were contacted to an external potentiometer by a method similar to that described in reference 1. After the thermocouple was installed, the piston cap was locked in place by two safety-wired set screws.

The oil-cooled piston as used in these tests was for the purpose of providing a variation in the piston temperature and not for evaluating the merits of an oil-cooled piston as such. Consequently, the procedure of blocking the oil passages to the piston rather than substituting a conventional piston to obtain the higher piston temperature was justified.

Supercharged knock-limited tests were made in the CFR engine with and without piston cooling for S-3 reference fuel, AN-F-28, Amendment-2, aviation gasoline and AN-F-28 plus 2 percent xylidines by weight. These fuels were chosen to obtain results on a standard reference fuel, a current aviation gasoline, and an aviation gasoline of greater temperature sensitivity as represented through the addition of 2 percent xylidines by weight to the aviation gasoline.

Tests were run at a compression ratio of 7.0 with inlet-air temperatures of 150° F and 250° F and at a compression ratio of 8.0 with an inlet-air temperature of 250° F to determine the effect of piston-head temperature on knock-limited power under conditions of increasing severity and at fuel-air ratios ranging from 0.055 to 0.120. Each fuel was tested on the same day at these three combinations of compression ratio and inlet-air temperature with piston cooling. On the previous or the following day, the same tests were performed without piston cooling.

The following engine conditions were maintained constant:

Engine speed, rpm	2000
Inlet-coolant temperature, °F	250
Spark advance, degrees B.T.C.	35
Oil temperature, °F	175

RESULTS AND DISCUSSION

Figures 5 to 7 are plots of knock-limited indicated mean effective pressure, indicated specific fuel consumption, knock-limited inlet-air pressure, and piston-head temperature plotted against fuel-air ratio. The curves for knock-limited indicated mean effective pressure were computed from the faired curves for indicated specific fuel consumption in conjunction with the approximately linear relationships between fuel flow and air flow at the knock limit. This method of fairing the data gave good agreement with the test points except for the data shown in figure 6(c) at a fuel-air ratio of 0.07. The performance curves show the extent to which a decrease in piston-head temperature increased the knock-limited indicated mean effective pressure except at high fuel-air ratios but did not affect the indicated specific fuel consumption or the value of fuel-air ratio at which minimum knock-limited indicated mean effective pressure occurred (with the exception of the data in figure 7(b)).

The piston-head temperature decreased approximately 80° F during each test. The effects of a constant amount of piston cooling on knock for the three fuels at three sets of engine conditions were thus determined.

Although the oil consumption of the CFR engine was so small that no change was observed accompanying piston cooling, it is probable that more oil entered the combustion chamber when the piston was oil-cooled than when it was not cooled. From tests of an unsupercharged CFR engine, Stacey (reference 2) concluded that changes in knock rating of as much as 1 octane number may be attributed to different rates of oil consumption. Recent work by the NACA indicated that an addition of 2.5 percent by weight of oil to the gasoline of a supercharged CFR engine lowered the knock-limited indicated mean effective pressure from 10 to 18 percent but had no effect on the indicated specific fuel consumption. If the oil consumption were controlled and maintained constant, it would be reasonable to assume that the increase in knock-limited indicated mean effective pressure obtained by the decrease in piston-head temperature would be somewhat more than presented in the present investigation.

The percentage increase in knock-limited indicated mean effective pressure has been cross-plotted against fuel-air ratio in figure 8 for the three fuels at each set of engine conditions tested. Because of the permissible variations in fairing the curves determined by the knock-limited data, the plots in figure 8 are drawn to represent approximate values. The increase was from about 5 to 18 percent, near the stoichiometric mixture, and became negligible at high fuel-air ratios. The appreciation was greater for AN-F-28,

Amendment-2, aviation gasoline and AN-F-28 plus 2 percent xylidines by weight than for S-3 reference fuel at all engine conditions tested.

Figure 9 is a cross plot of the fuel-air ratio against the ratio of the increase in knock-limited indicated mean effective pressure allowed per degree Fahrenheit decrease in piston-head temperature to the increase in knock-limited indicated mean effective pressure allowed per degree Fahrenheit decrease in inlet-air temperature. Curves have been cross-plotted for the three fuels at the two inlet-air temperatures with a compression ratio of 7.0. This figure shows that a decrease in piston-head temperature permitted approximately 30 percent of the increase in knock-limited indicated mean effective pressure that was allowed by an equal decrease in inlet-air temperature except at high fuel-air ratios.

The procedure of changing the wrist pin between tests with and without piston cooling could possibly shift the knock-limited engine performance. The general agreement, however, in the trends of improved knock-limited performance accompanying piston cooling for all the fuels and the engine conditions tested shows that the data are significant.

CONCLUSION

For all but the high fuel-air ratios tested, the decrease in piston-head temperature permitted approximately 30 percent of the increase in knock-limited indicated mean effective pressure that was allowed by an equal decrease in inlet-air temperature.

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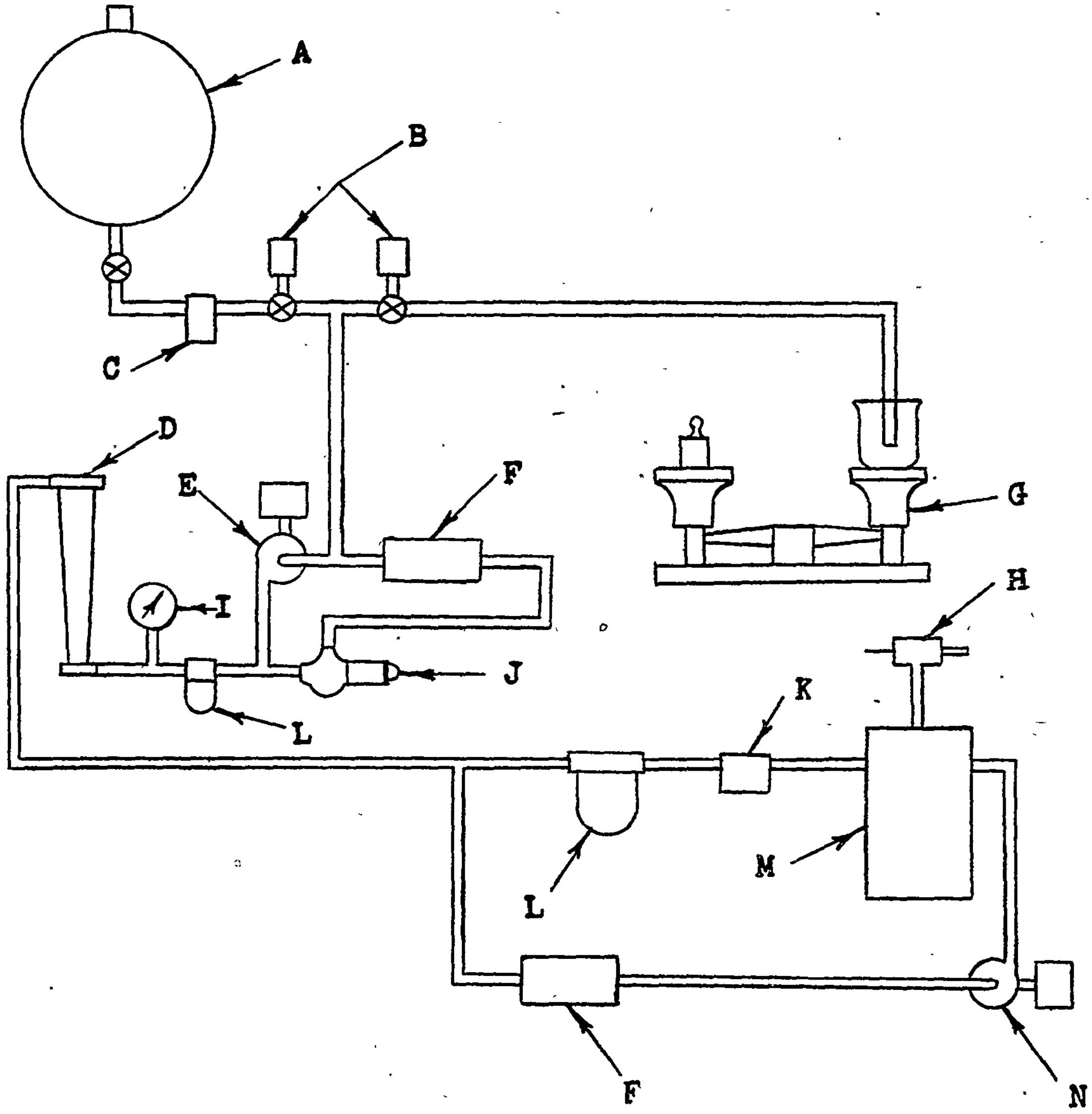
REFERENCES

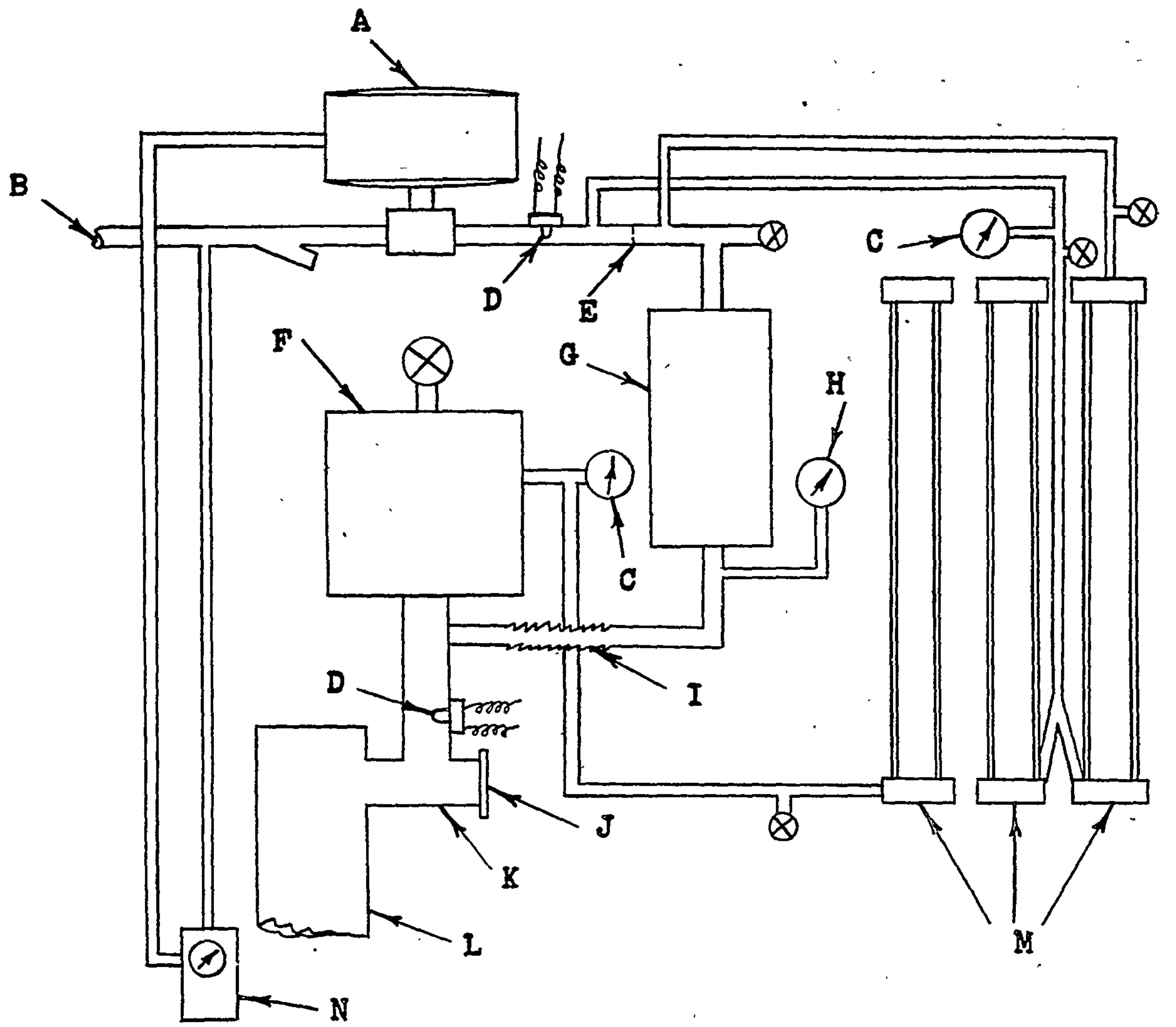
1. Pinkel, Benjamin, and Manganiello, Eugene J.: A Method of Measuring Piston Temperatures. NACA TN No. 765, 1940.

2. Stacey, H. R.: Effect of Oil Consumption and Temperature on Octane-Number Ratings. SAE Trans., vol. 26, 1931, pp. 457-458.



A	Fuel supply tank	H	Fuel-injection nozzle
B	Solenoid valves	I	Pressure gage
C	Strainer	J	Pressure-relief valve
D	Rotameter	K	Surge eliminator
E	Primary fuel pump	L	Filter
F	Cooler	M	Injection pump
G	Fuel-weighing stand	N	Circulating pump

Figure 1. - Diagram of fuel system.



A Air-pressure regulator
B Air supply
C Pressure gage
D Thermocouple
E Air-measuring orifice
F Surge tank
G Air preheater
H Dial thermometer
I Flexible coupling
J Opening for fuel-injection nozzle
K Inlet manifold
L Engine cylinder
M Manometers
N Pilot valve for pressure regulator

Figure 2. - Diagram of inlet-air system.

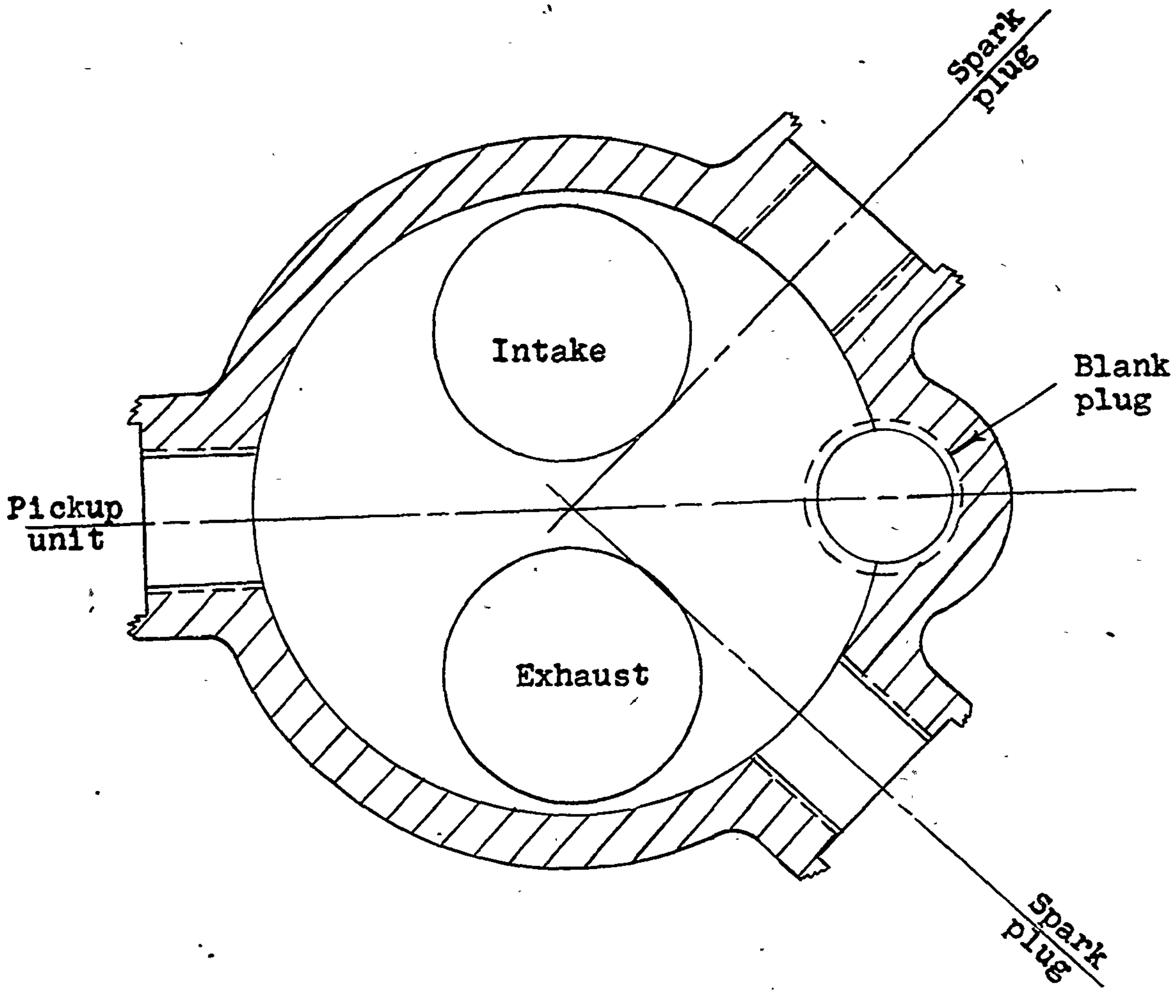


Figure 3. - Location of spark plugs and knock pickup unit in the CFR cylinder.

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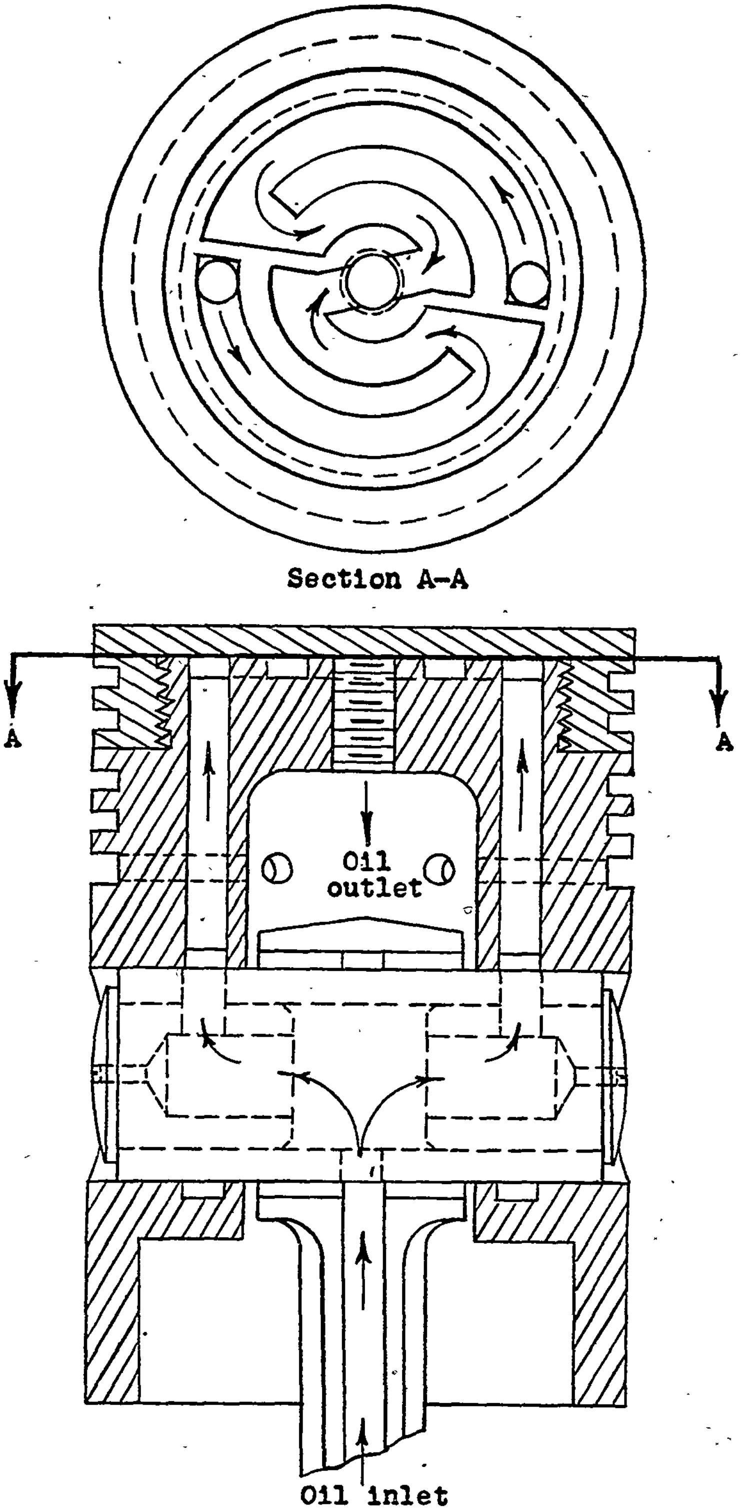
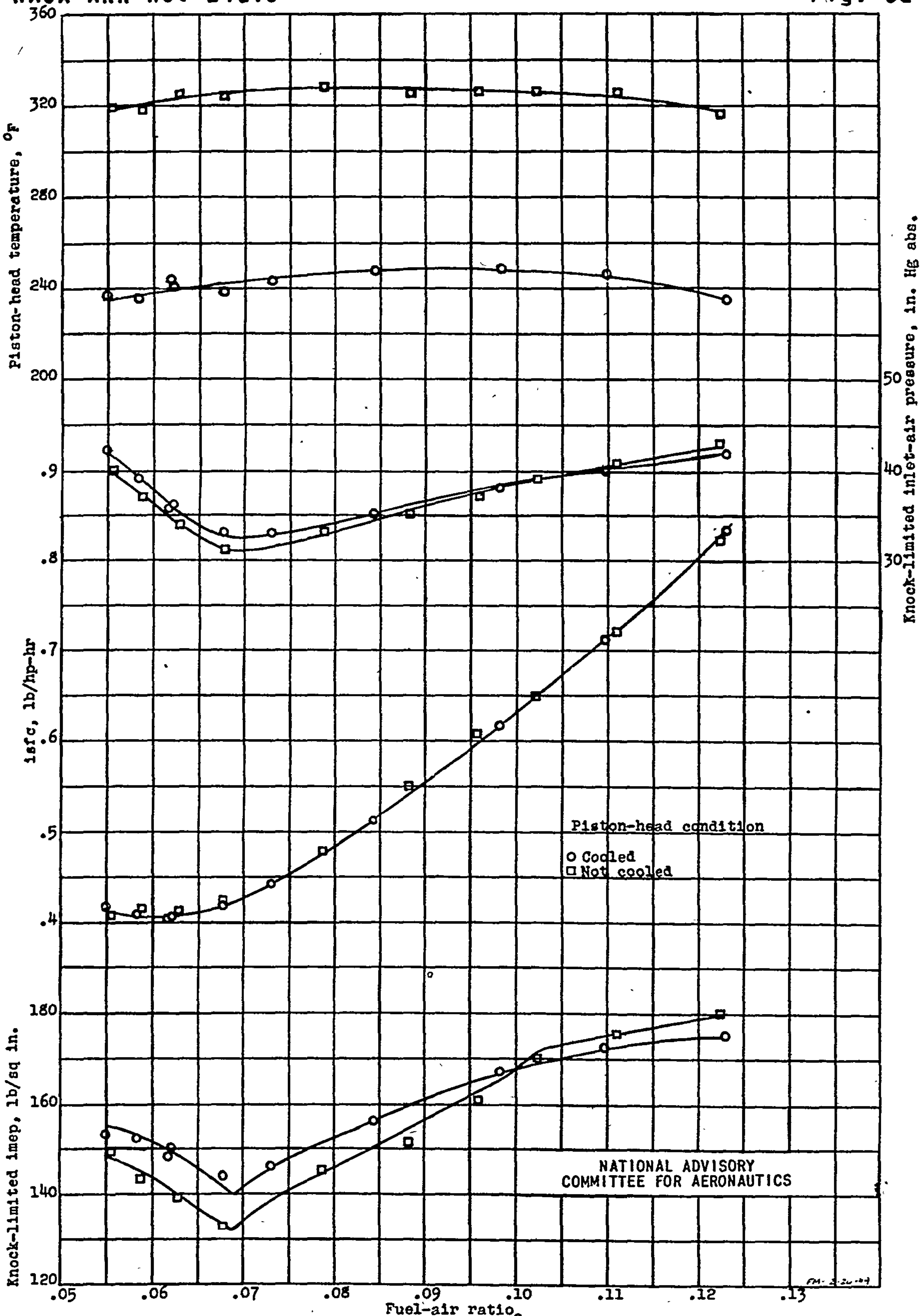
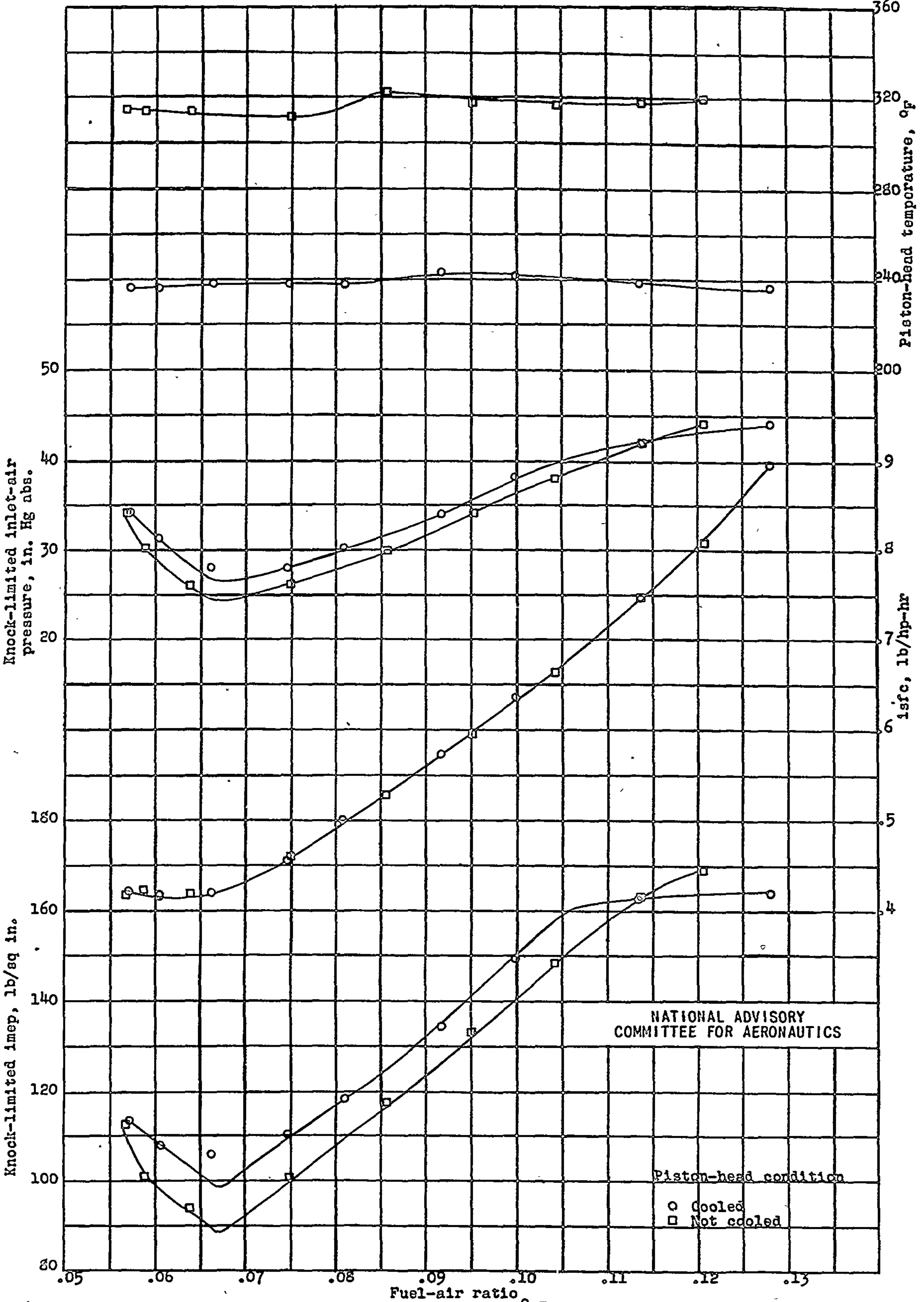


Figure 4. - Diagram of oil-cooled piston.

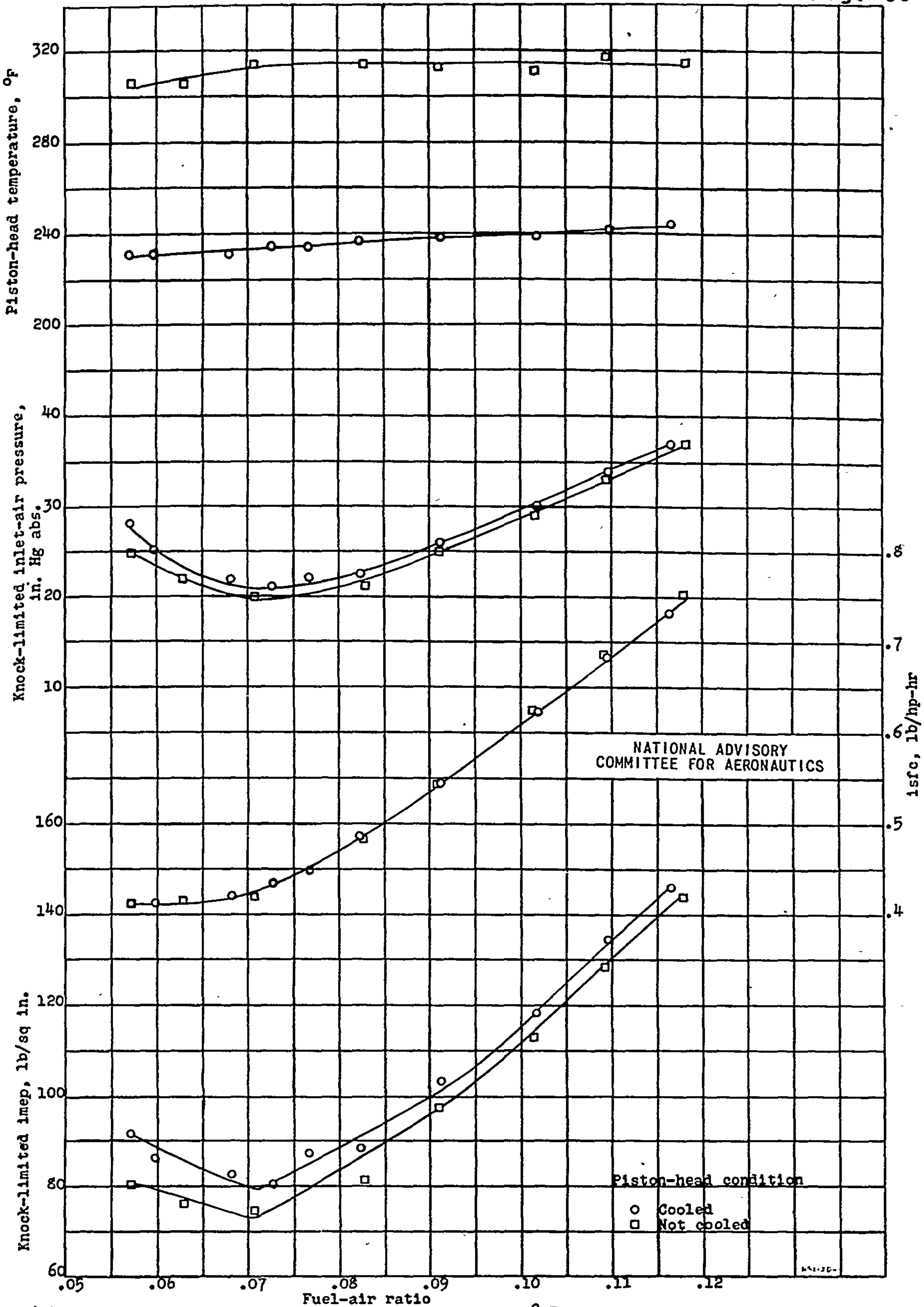


(a) Compression ratio, 7.0; inlet-air temperature, 150° F.

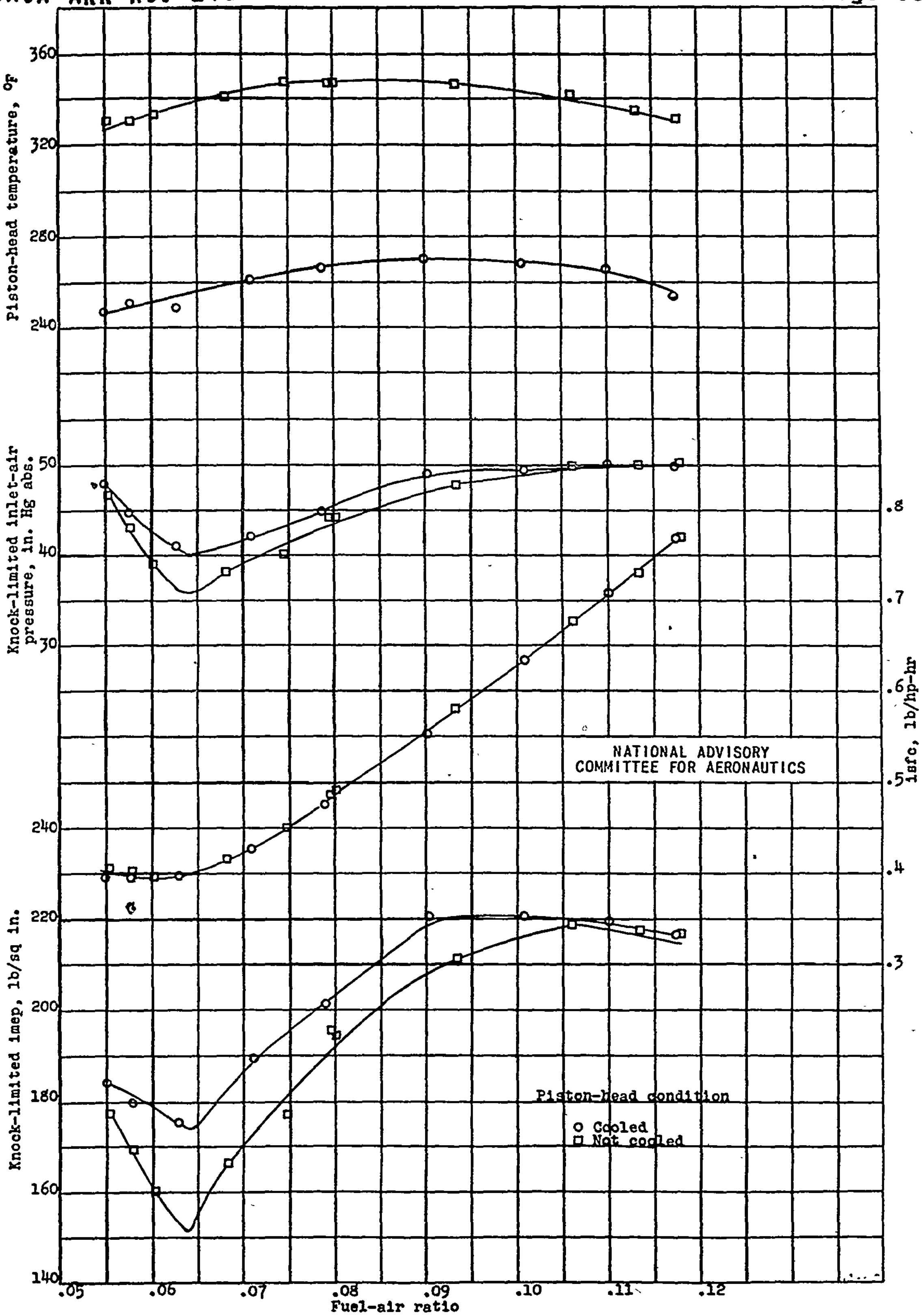
Figure 5. - The effect of piston-head temperature on the knock-limited CFR engine performance of S-3 reference fuel. Engine speed, 2000 rpm; inlet-coolant temperature, 250° F; spark advance, 35° B.T.C.; oil temperature, 175° F.



(b) Compression ratio, 7.0; inlet-air temperature, 250° F.
Figure 5. - Continued.

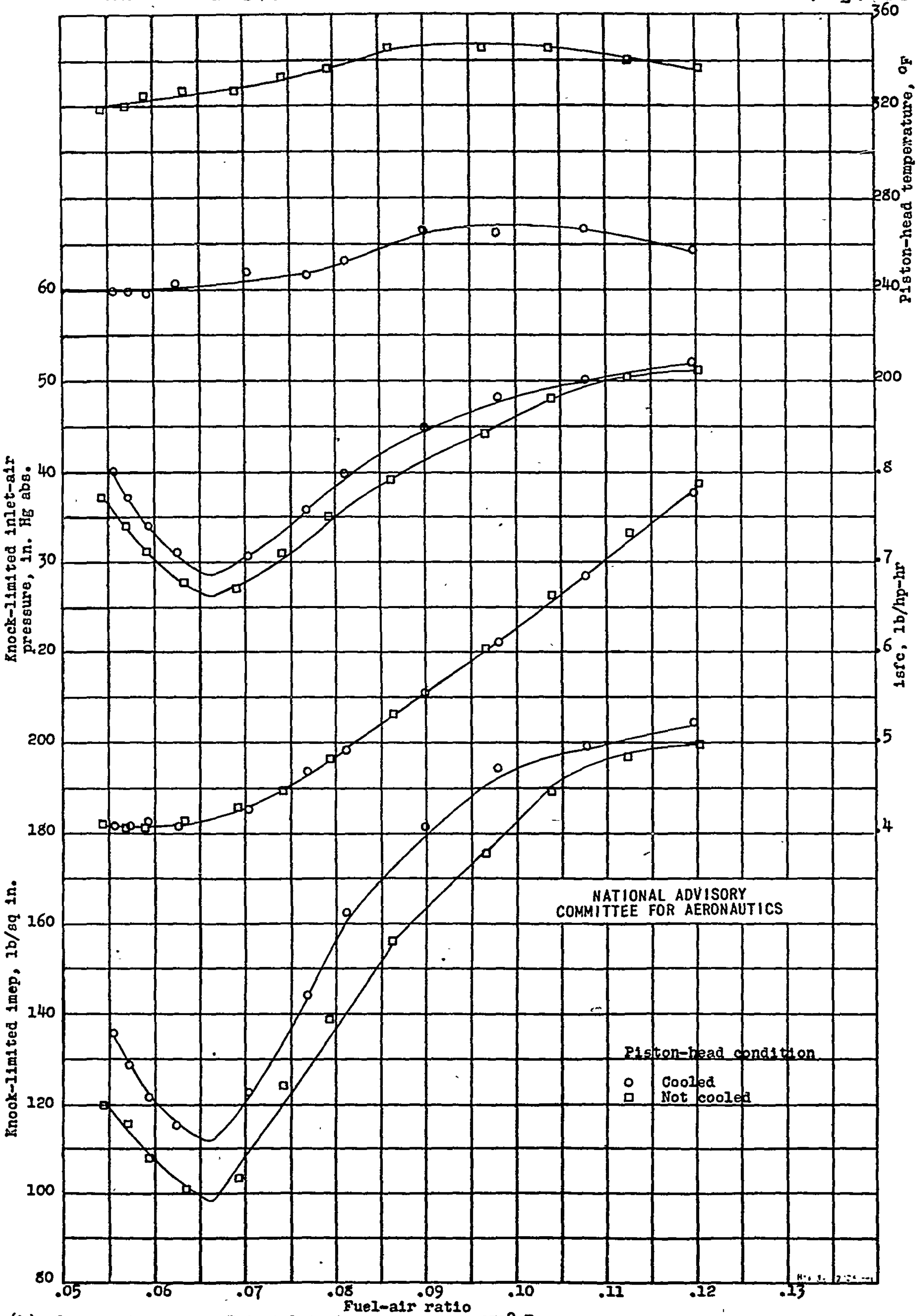


(c) Compression ratio, 8.0; inlet-air temperature, 250° F.
Figure 5. - Concluded.

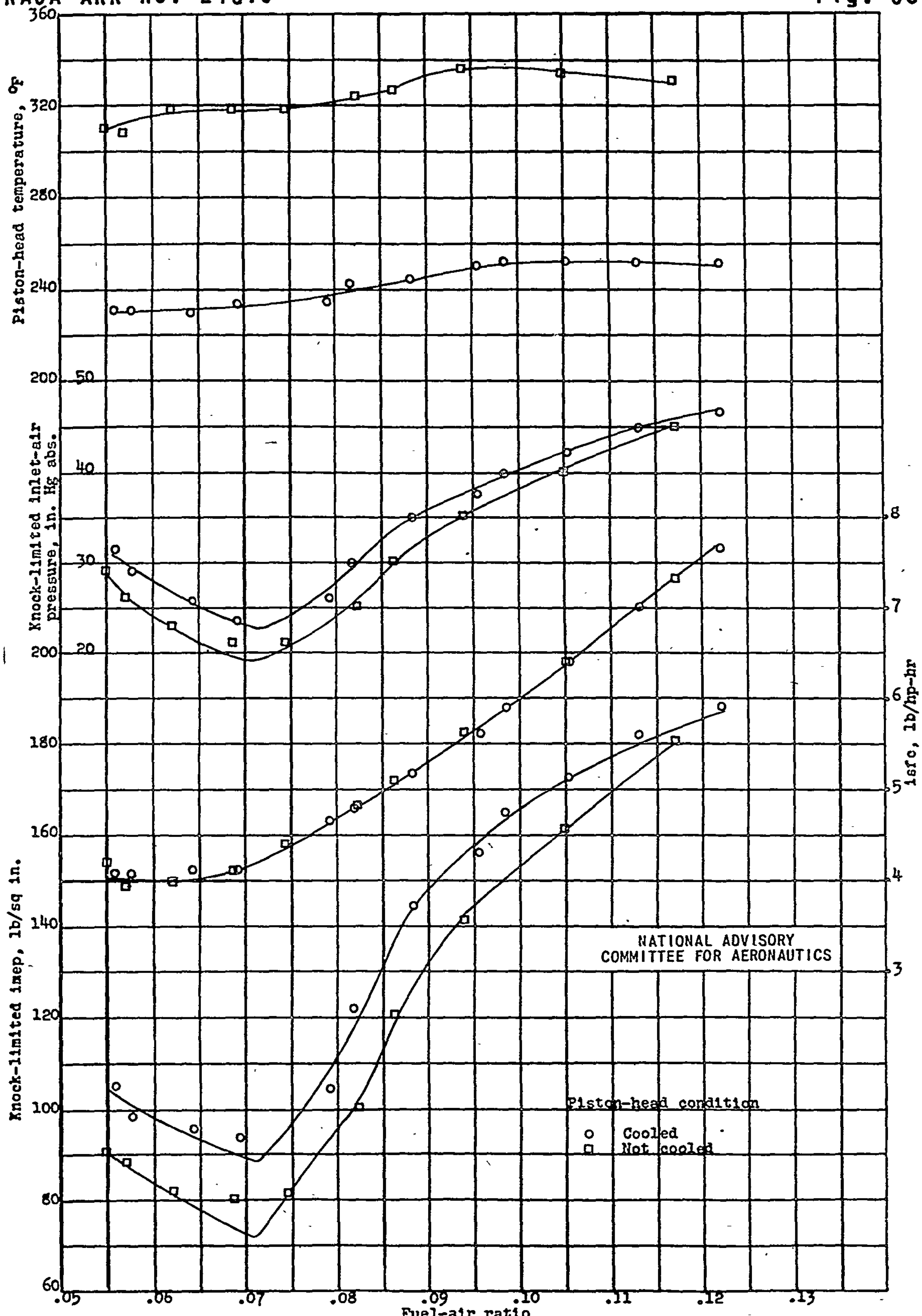


(a) Compression ratio, 7.0; inlet-air temperature, 150° F.

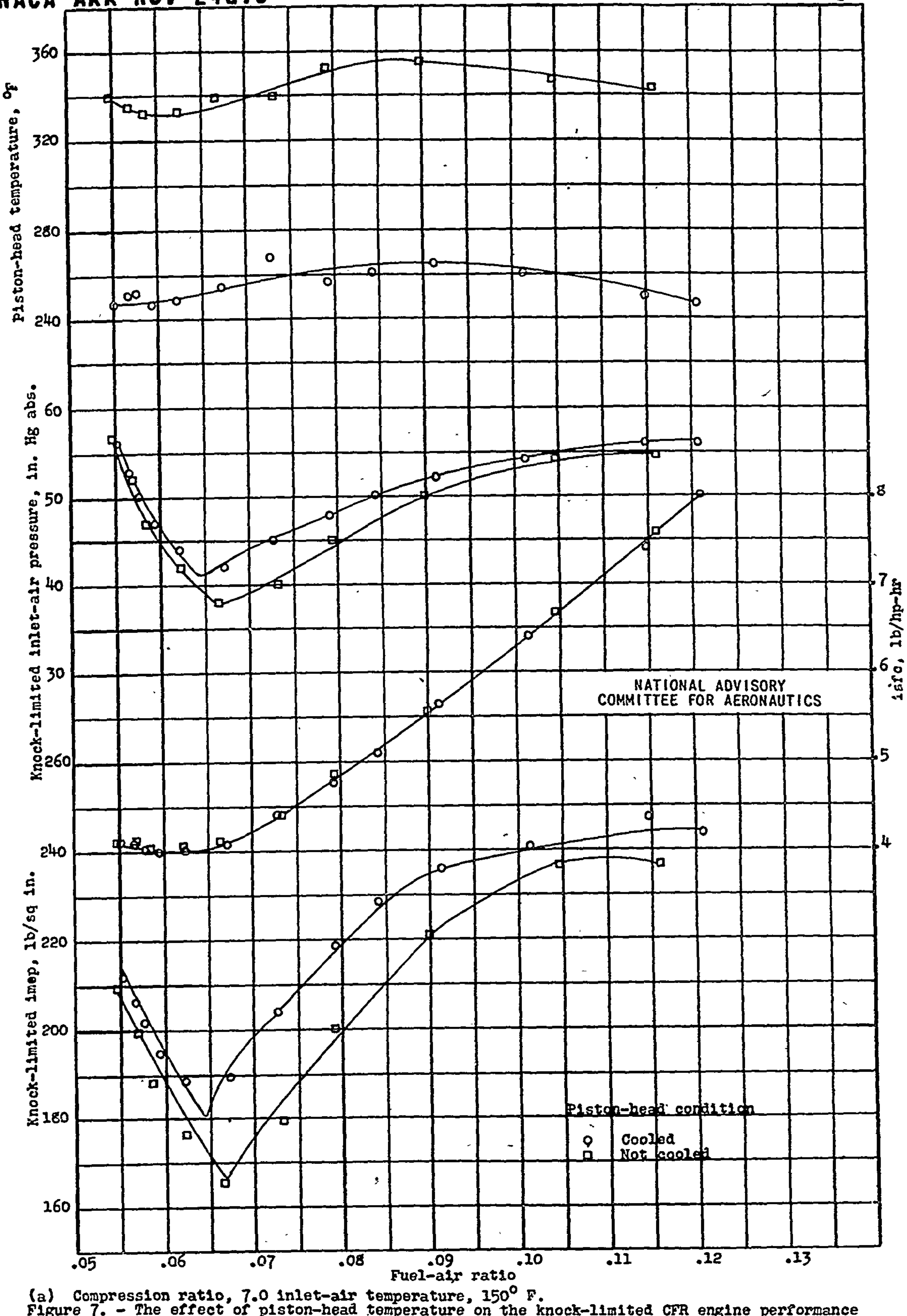
Figure 6. - The effect of piston-head temperature on the knock-limited CFR engine performance of AN-F-28, Amendment-2, aviation gasoline. Engine speed, 2000 rpm; inlet-coolant temperature, 250° F; spark advance, 35° B.T.C.; oil temperature, 175° F.



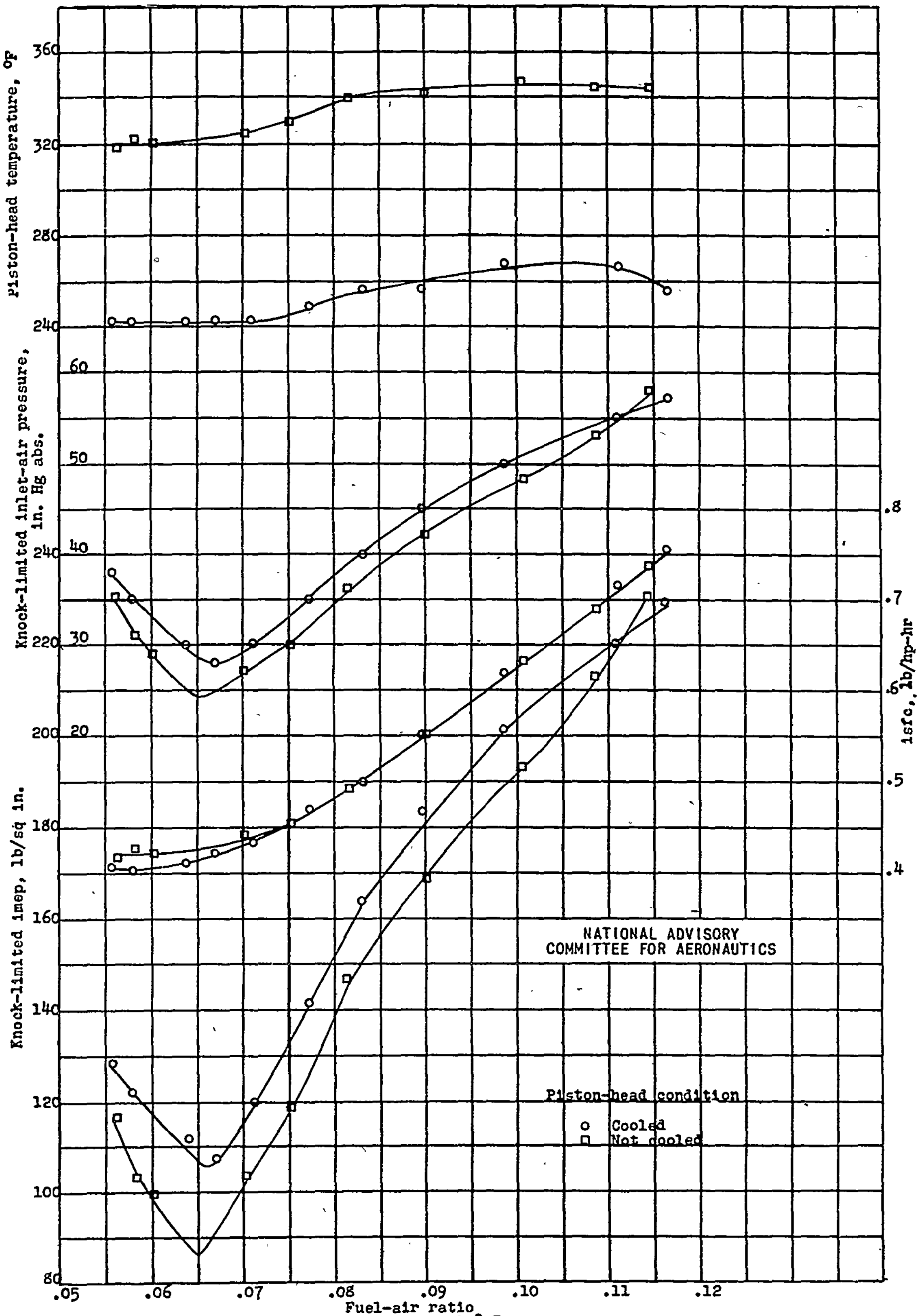
(b) Compression ratio, 7.0; inlet-air temperature, 250° F.
Figure 6. - Continued.



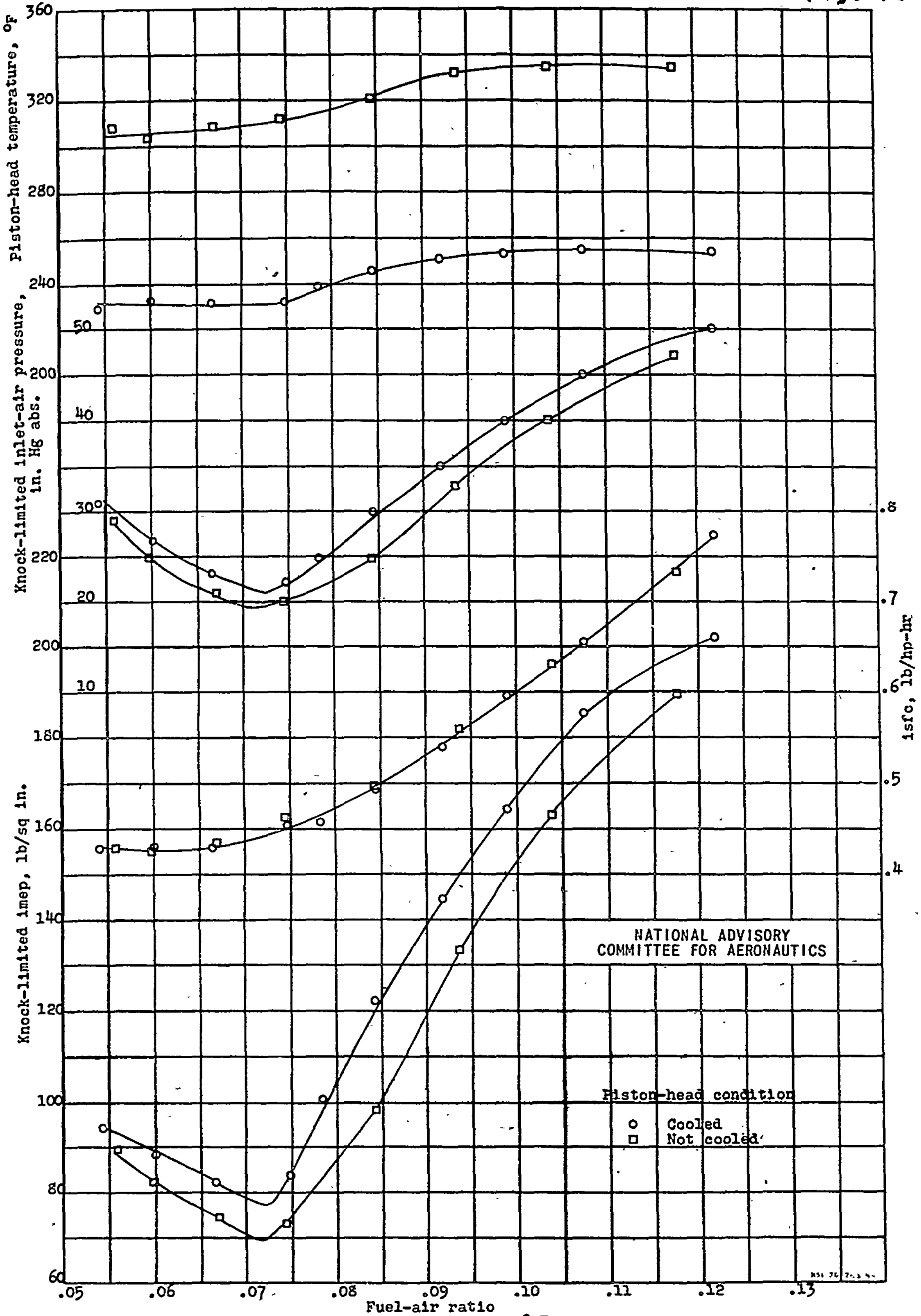
(c) Compression ratio, 8.0; inlet-air temperature, 250° F.
Figure 6. - Concluded.



(a) Compression ratio, 7.0 inlet-air temperature, 150° F.
Figure 7. - The effect of piston-head temperature on the knock-limited CFR engine performance of AN-F-28, Amendment-2, aviation gasoline plus 2 percent xylidines by weight. Engine speed, 2000 rpm; inlet-coolant temperature, 250° F; spark advance, 35° B.T.C.; oil temperature, 175° F.



(b) Compression ratio, 7.0; inlet-air temperature, 250° F.
Figure 7. - Continued.



(c) Compression ratio, 8.0; inlet-air temperature, 250° F.
Figure 7. - Concluded.

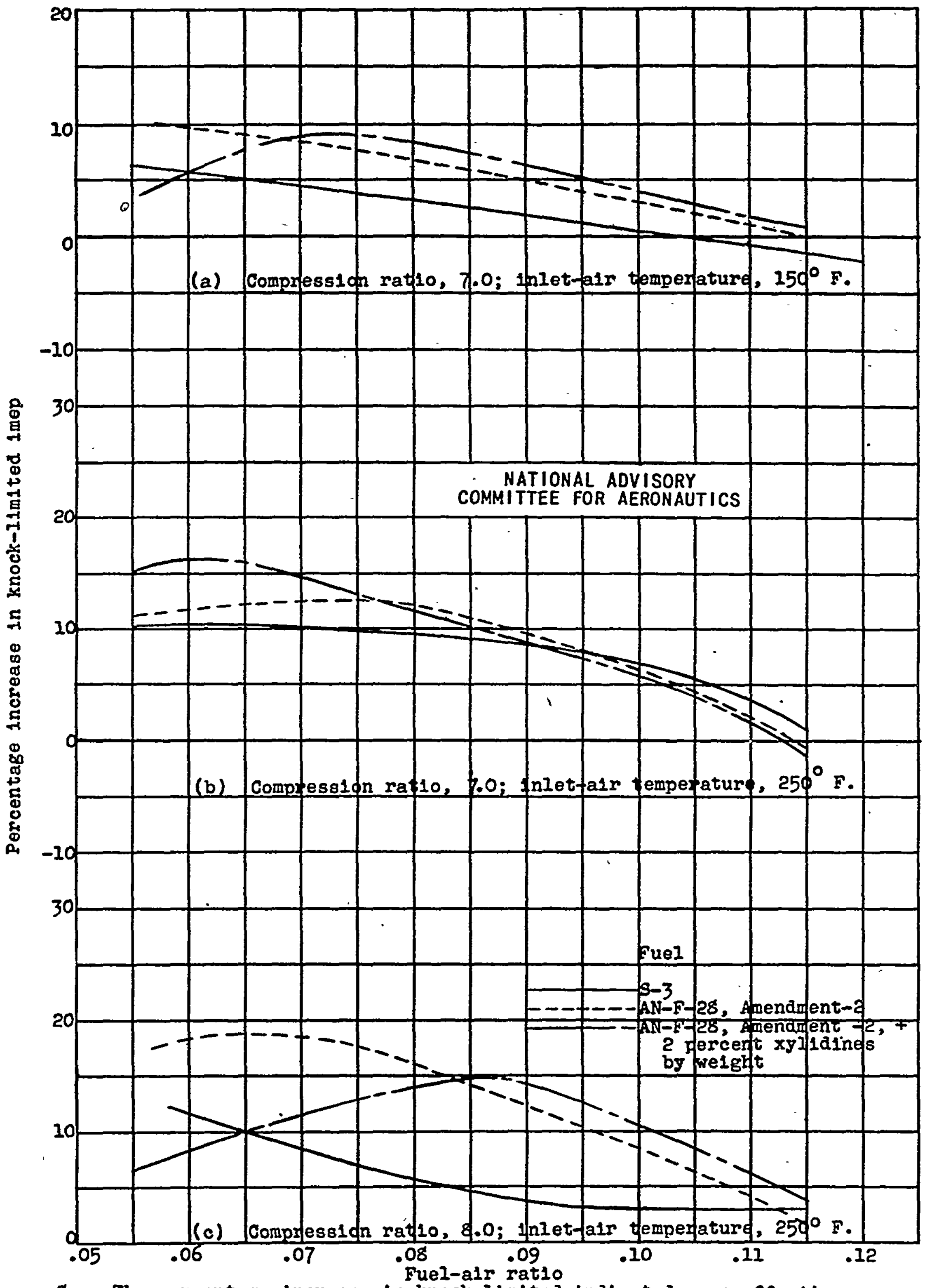


Figure 8. - The percentage increase in knock-limited indicated mean effective pressure for each of three fuels allowed by approximately 80° F piston cooling. CFR engine; engine speed, 2000 rpm; inlet-coolant temperature, 250° F; spark advance, 35° B.T.C.; oil temperature, 175° F.

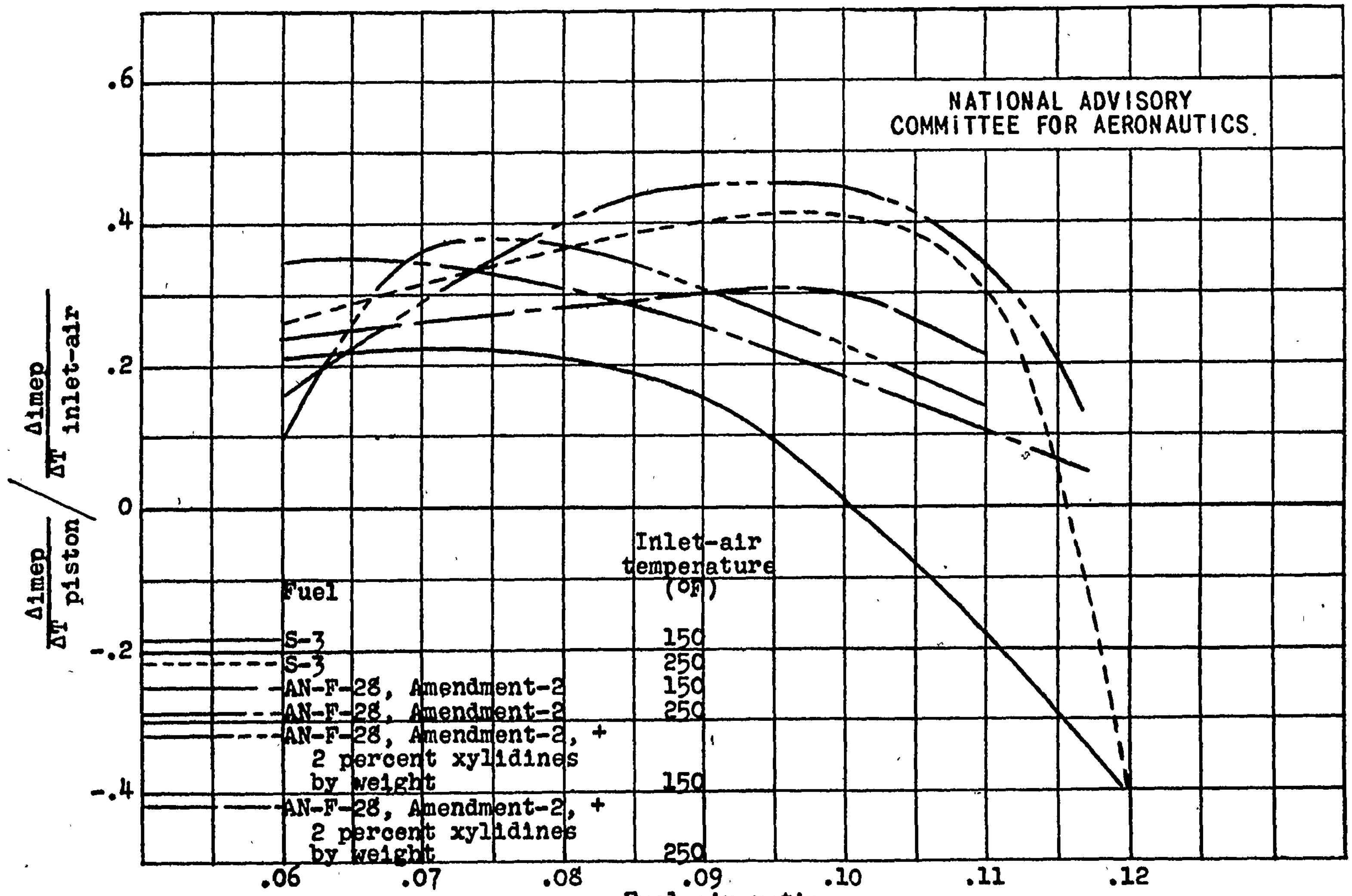


Figure 9. - A comparison between the effects of piston cooling and lowering of inlet-air temperature on the knock-limited indicated mean effective pressure. CFR engine; engine speed, 2000 rpm; compression ratio, 7.0; inlet-coolant temperature, 250° F; spark advance, 35° B.T.C.; oil temperature, 175° F.